CONTROL OF MOISTURE CONTENT AND SHRINKAGE OF WOOD

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CONTROL OF MOISTURE CONTENT AND SHRINKAGE OF WOOD

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U. S. Department of Agriculture

Equilibrium Moisture Content

Any piece of wood will give off or take on moisture from the surrounding atmosphere until the amount of moisture in the wood balances that in the atmosphere. The moisture in the wood at the point of balance is called the equilibrium moisture content, and is expressed as a percentage of the oven-dry weight of the wood.

Assuming constant temperature, the ultimate moisture content that a given piece of wood will attain depends entirely upon the relative humidity of the atmosphere surrounding it. The relationship between equilibrium moisture content and relative humidity at different temperatures is shown in table 1. For practical use in control of dry-kiln or storage-room conditions, comparative values are shown for different dry-bulb temperatures and for different wet-bulb depressions. For example, at a dry-bulb temperature of 70° F. and a wet-bulb depression of 9° F. below dry-bulb temperature, which corresponds to a relative humidity of 59 percent, the equilibrium moisture content of the wood is 10.9 percent. Changes in relative humidity in the higher ranges cause greater changes in equilibrium moisture content than do corresponding changes in the lower ranges of relative humidity. Although different species exhibit some differences in their reactions to relative humidity, for practical purposes table 1 applies to the wood of any species.

Wood in service is exposed to daily and seasonal changes in relative humidity. Thus, wood is virtually always undergoing at least slight changes in moisture content because of its tendency to come to a balance with the relative humidity of the surrounding air. The changes are gradual and may be further retarded by protective coatings, such as varnish or paint. The practical objective of all correct seasoning, handling, and storing methods is to minimize moisture content variations in wood in service by fabricating or installing the wood at a moisture content corresponding to the average atmospheric conditions to which it will be exposed.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Recommended Moisture Content

The percentages of moisture content recommended here for wood are selected primarily for the purpose of reducing changes in moisture content to a minimum, thereby minimizing dimensional changes after the wood is put into service (6)[2]. The service conditions to which the wood will be exposed, whether outdoors, in unheated buildings, or in heated buildings, should be considered in determining seasoning requirements.

Timbers

Ordinarily, a timber should be seasoned to as low a moisture content as it will ultimately come to in service, or as near this condition as practical. While this optimum may be possible in small and medium-sized timbers, it is seldom possible to obtain fully seasoned large timbers. Where it is necessary to use large timbers, such as in warehouses, bridges, trestles, and derricks, some shrinkage of the assembly should be expected and the design of the structure should take account of this condition in such a way as to minimize shrinkage effects.

Material to be used for roof trusses, arches, laminated floors, heavy plank flooring, bridge members, derricks, and similar purposes should be seasoned to a moisture content corresponding to service conditions, unless the large size of the timbers makes seasoning impractical.

Lumber for Exterior or Interior Service

The moisture content requirements for finish lumber or wood products used inside heated buildings are more exacting than those for lumber used outdoors or in unheated buildings. This is due to the higher character of the service required and also to the lower relative humidity conditions encountered within heated buildings than outdoors. Table 2 and figure 1 show the recommended moisture content values and tolerances for wood used in interior and exterior parts of heated buildings. The values for exterior trim and siding can be applied to lumber used outdoors and in unheated buildings.

It is the general commercial practice to kiln dry some wood products, such as flooring (11) and furniture wood, to a slightly lower moisture content than service conditions demand, counting on a moderate increase in moisture content during the storage and manufacturing periods. This practice is intended to assure a uniform distribution of moisture among the individual pieces. Common grades and dimension are not ordinarily seasoned to the moisture content values indicated in table 2. The design of the structure should take account of this condition in such a way as to minimize shrinkage effects.

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[2]Underlined numbers in parentheses refer to Literature Cited at end of report.

Veneer and Plywood

When veneers are glued together with ordinary glues to make plywood, they absorb large quantities of moisture. To keep the final moisture content low and to minimize redrying of the plywood, the initial moisture content of the veneer should be as low as practical. Very dry veneer, however, is difficult to handle without cracking, so that the minimum practical moisture content is about 4 percent. After being glued, plywood intended for interior service should be redried to the moisture content values given in table 2 for interior lumber. If adhesives containing no water are used, the veneer need only be dried to a moisture content in accordance with its service requirements, and redrying is unnecessary.

Shrinkage of Wood

Wood, like many other materials, shrinks as it loses moisture and swells as it absorbs moisture.

Wood from the tree may contain from 30 to 300 percent water (3, 9), based on the weight of the oven dry wood. This water may be separated roughly into two parts, that contained as free water in the cell cavities and intercellular spaces of the wood, and that held as adsorbed water in the capillaries of the walls of such wood elements as fibers and ray cells. The adsorbed water is of primary interest in the consideration of shrinkage. When all of the free water is removed but all of the adsorbed water remains, wood is said to have reached the fiber-saturation point. The fiber-saturation point is approximately 30 percent moisture content for all species.

Shrinkage occurs if the moisture content is reduced to a value below that of the fiber-saturation point, and is proportional to the amount of moisture lost below 30 percent moisture content (8). Wood dried to 15 percent moisture content has attained about one-half of the total shrinkage possible. For each 1 percent loss in moisture content, the wood shrinks about one-thirtieth of the total. Likewise, for each 1 percent increase in moisture content of 1 percent the piece swells about one-thirtieth of the total swelling possible. The total swelling is equal numerically to the total shrinkage. Shrinking and swelling are expressed as percentages based on the green or initial dimensions of the wood.

As a piece of wood dries, the outer parts are reduced to a moisture content below the fiber-saturation point considerably sooner than the inner parts. Thus, the whole piece may show some shrinkage before the average moisture content reaches the fiber-saturation point.

Wood shrinks most in the direction of the annual growth rings (tangentially), somewhat less across these rings (radially), and very little, as a rule, along the grain (longitudinally) (2). The combined effects of radial and tangential shrinkage on the shape of various sections in drying from the green condition are illustrated in figure 2. Shrinkage causes cross-grained boards to warp and shorten.

Table 3 gives the average tangential, radial, and volumetric shrinkage for numerous species in drying from the green condition to 15, 6, and 0 percent moisture content.

In general, the heavier species of wood shrink more across the grain than lighter ones. Heavier pieces also shrink more than lighter pieces of the same species. Hardwoods generally shrink more than softwoods. The ratio of total radial to total tangential shrinkage ranges from 1:1.2 to 1:2.6. Species, however, do not always conform to the general shrinkage pattern. For example, basswood is a light wood, but shrinks considerably more than black locust, a heavy wood.

Values for longitudinal shrinkage are not given in table 3. The total longitudinal shrinkage of normal wood usually ranges from 0.1 to 0.3 percent of the green dimension. Exceptionally light wood of any species tends to shrink excessively in length.

Abnormal types of wood, known as compression wood and tension wood, also shrink more along the grain than does normal wood. Compression wood occurs in softwoods and tension wood in hardwoods. Longitudinal shrinkage varies widely with the form of compression wood. In borderline forms that differ only slightly from normal wood, lengthwise shrinkage is but a little more than that of normal wood. Pronounced forms, on the other hand, shrink 5 to 10 times as much as normal wood of the conifers. In the same way, pieces of hardwoods with only a few tension-wood fibers have nearly the same longitudinal shrinkage as normal wood, but if many of these fibers are present, longitudinal shrinkage is considerably greater than that of normal wood.

Compression wood or tension wood may occur in the same board with normal wood, so that internal stresses are set up that cause lengthwise distortion of boards. If the boards contain moderate to pronounced forms of compression wood or moderate to large numbers of tension wood fibers, these stresses are large and serious warping usually results. Even borderline forms of compression wood or tension wood may interfere with the usefulness of pieces in products that permit only small tolerance with respect to warping.

Although theoretically the normal moisture content-shrinkage relation may be considered a direct one from zero shrinkage at fiber-saturation point to maximum shrinkage at zero moisture content, actually the relationship is more like that shown in figure 3. For some shrinkage calculations, however, a straight-line relation may be assumed without too great an error. For example, assume that a piece of flat-sawed southern yellow pine sheathing at 12 percent moisture content is dried to 7 percent. According to the curve in figure 3 marked tangential, the shrinkage from the green condition to a moisture content of 7 percent would be 5 percent while that from green to 12 percent would be 3-1/2 percent, for a difference of 1-1/2 percent. If a straight-line relation is used, the shrinkage would equal 5/30 or 1/6 of the total tangential shrinkage of 6.67 percent, or 1.11 percent of its width.

Since the shrinkage values and curves represent averages, the actual shrinkage of a board may vary somewhat from them.

Design Factors Affecting Shrinkage in the Structure

Structural Lumber in Frame House Construction

The most effective method of minimizing shrinkage or settlement in the house frame is to use structural lumber seasoned to suit the use requirements as shown in table 2. Any of the standard forms of construction (5, 12, 13) can be used if the joists and studs are seasoned to the recommended moisture content.

If structural lumber has a moisture content higher than that recommended, consideration should be given to the type of framing that will give best results. Construction methods that minimize the use of wood across the grain in vertical supports also minimize shrinkage. For example, if joists are run over the top of a girder (fig. 4), the vertical height of wood used across the grain is great, and opportunity for subsequent shrinkage may be proportionate. On the other hand, if the joists bear on ledger strips nailed to the sides of a girder (fig. 5), the vertical inches of side grain are reduced and possible shrinkage reduced accordingly. In this type of construction, the joists may be notched over the nailing strip, or preferably the depth of the girder can be equal to the depth of joist plus the nailing strip. The use of metal post caps instead of wood bolsters likewise reduces total shrinkage.

The platform type of construction (fig. 6) is intended to equalize but not to minimize shrinkage, and it accomplishes the purpose satisfactorily within the building, even where the material used is only partially seasoned. Vertical shrinkage at the floor lines, however, presents a difficult problem at chimneys and on outside walls of brick or stone veneer or stucco that are unbroken. Where the design calls for a break, such as an overhanging second floor or a change in materials, provision for shrinkage is readily made.

Vertical shrinkage in the exterior walls is held to a minimum in the standard balloon (fig. 7) type of construction, and this system is preferable where exterior walls are brick veneered or stuccoed without a break at the intervening floor line.

Interior bearing walls are of either the platform type or the type in which the first-floor studs extend to the basement girder and, where possible, the second-floor studs extend to the top of the first-floor partition cap. For one-story structures the platform system is preferable, as it permits both the bearing walls and the nonbearing walls, which are supported by the joists, to settle uniformly. For the same reason, the platform type may be used for the interior walls of the second floor in two-story structures having exterior walls of balloon construction. If the balloon frame is used for exterior walls and platform construction for interior bearing walls, shrinkage at the interior walls of the first-floor structure plus that of the second-floor structure may be sufficient to cause plaster cracks and other evidence of shrinkage, particularly on the second-floor cross walls. Extending the bearing partition studs of the first floor down to the top of the basement girder reduces the shrinkage that causes plaster cracks on the second floor. This system, however, results in uneven shrinkage between the cross walls and the bearing

partition on the first floor. This shrinkage may be sufficiently uneven to cause plaster cracks at the junction of such walls unless thoroughly seasoned material is used.

If the framework of a house is allowed to dry before the house is plastered, cracking of the plaster due to shrinkage can be reduced to some extent (10). If dry-wall construction is used, the framework should be allowed to dry before the interior wall lining and interior trim are installed. Permitting the structure to settle before the inner parts are installed diminishes the damage that may result from the shrinking and settling. Where plaster is used, some of the moisture contained in the plaster goes into parts of the structure that are already in place. This moisture should be removed before finish and flooring are installed by heating and ventilating the building, except in dry, hot weather.

Heavy Timber Construction

In heavy timber construction, a certain amount of shrinkage is to be expected. If not provided for in the design, it may cause weakening of joints, affect floor levels, and be otherwise objectionable. One means of eliminating part of the shrinkage in mill buildings and similar structures is the use of metal post caps, whereby the upper column is separated from the lower column only by the metal in the post cap. This method eliminates the shrinkage that occurs if the girder is used as a bearing for the upper column. The same thing is accomplished by using a cast-iron pintle resting upon a metal post cap over the top of the lower column to support the upper column. This method also allows the girder to bear over the lower post. The stem of the pintle, being encased, is protected from fire, and as the girder bears over the column, the cap is less likely to fail than if the girder were supported entirely by the cap.

Where joist hangers are used, the top of the joist, when installed, should be slightly above the top of the girder; otherwise when the joist shrinks in the stirrup, the floor over the girder will be higher than that bearing upon the joist. Laminated floor material can easily be properly seasoned and shrinkage minimized accordingly, because each piece is of relatively small cross section.

Interior Finish

The normal seasonal changes in the moisture content of interior finish are not enough to cause serious dimensional change if the stock is properly seasoned and the woodwork is carefully designed and assembled. Large members, such as ornamental beams, cornices, newel posts, stair stringers, and hand rails, should be built up from comparatively small pieces. Wide, plain surfaces, such as table tops, counter tops, and panels, should be crossbanded. Door and window trim and base should be hollow-backed. Backband trim, if mitered at the corners, should be glued and splined before erection, otherwise, butt joints should be used for the wide faces. Large, solid pieces, such as knotty pine panels, should be stained and finished as much as possible

before erection and should be so installed that the panels are free to move across the grain.

Seasoning of Lumber

Moisture in Wood

The moisture in wood, commonly called "sap," may for all practical purposes in the drying of wood (3, 7) be considered as water alone. Table 4 gives some moisture content values for green heartwood and sapwood of various species. The values shown may be considered average, and considerable variation from these values may be expected, in individual trees and single boards, particularly in sapwood.

Sawmills cutting softwoods generally grade their products at the time of sawing. With few exceptions, timbers, dimension, and the lower grades of lumber are sent to the yard for air drying or are shipped green. The upper grades intended for interior finish and flooring are kiln dried because of the use requirements. At certain mills, some of the dimension and lower grades are partially kiln dried to hasten the seasoning process, to reduce the susceptibility to stain and decay, and to obtain the benefit of lowered freight charges. Sawmills cutting hardwoods commonly classify for size and grade at time of sawing and then send all stock to the air-drying yard. Ultimately, hardwood stock should be kiln dried before remanufacture, since it is used mostly where a low moisture content is required, as in cabinet work, interior finish, flooring, and furniture.

Air Drying

The principal advantages of air-dried wood over green wood (3, 7) are: reduction in weight, with a resulting decrease in shipping costs; reduction in shrinkage, checking, honeycombing, and warping occurring in service; decrease in the tendency for blue stain and other forms of fungi to attack the wood; reduction in likelihood of attack by some forms of insects; increase in strength; and improvement in the capacity of the stock to hold paint or to receive preservative treatment.

Kiln Drying

Among the advantages of kiln drying over air drying are the following: Greater reduction in weight, and consequently in shipping charges; reduction in moisture content to any desired value, which may be lower than that obtainable through air drying; reduction in drying time below that required in air drying; and the killing of any stain or decay fungi or insects that may be in the wood.

Seasoning Defects

Obtaining material practically free of seasoning defects in the higher grades of lumber is insured by adherence to approved grading rules on the part of the manufacturers and knowledge of the material and its grades on the part of the user. Defects that sometimes develop in seasoning may be classified (3) into two main groups: (1) those caused by unequal shrinkage, which include checks, honeycomb, warp (fig. 8), loosening of knots, and collapse; and (2) those caused by the action of fungi, namely, molds, stains, and decay. Chemical brown stain, frequently known as yard or kiln brown stain, may also occur in some softwoods. It is a yellow to dark-brown discoloration and is apparently caused by the oxidation of water-soluble materials in the wood. So-called sticker stain is common in the air drying of both softwoods and hardwoods, and presumably is also caused by the concentration and oxidation of water-soluble materials in the wood.

These defects, with the exception of chemical stains, can be largely eliminated by proper practice in either air drying or kiln drying. Too rapidly drying will cause such defects as checking and splitting, whereas too slow drying under favorable temperatures will cause stain or decay. The grading rules of the various lumber associations specify the amount of defects permitted for the various grades of lumber. Most defects are specifically mentioned, but such defects as honeycombing and collapse are covered indirectly, as for example in softwood grading rules that state:

"When defects or blemishes not described in these grading rules are encountered, they shall be considered as equivalent to known defects according to their damaging effect upon the piece in the grade under consideration."

Honeycombing and collapse are more common in hardwoods than in softwoods and are more likely to occur during improper kiln drying than during air drying.

Moisture Content of Seasoned Lumber

The trade terms "shipping-dry," "air-dry," and "kiln-dried," although widely used, have no specific or agreed meaning with respect to quantity of moisture. The wide limitations of these terms as ordinarily used are covered in the following statements, which, however, are not to be construed as exact definitions:

Shipping-dry lumber.--Lumber that is partially air dried to reduce freight charges and may have a moisture content of 30 percent or more.

Air-dry lumber.--Lumber that has been exposed to the air for any length of time. If exposed for a sufficient length of time, it may have a moisture content ranging from 6 percent, as in summer in the arid Southwest, to 24 percent, as in the winter in the Pacific Northwest. For the United States as a whole, the minimum moisture content range of thoroughly air-dry lumber is 12 to 15 percent, and the average is somewhat higher.

Kiln-dried lumber.--Lumber that has been kiln-dried for any length of time. Properly kiln-dried lumber in the finish grades of softwoods and hardwoods intended for general use will ordinarily have a moisture content of 6 to 10 percent. Kiln-dried softwood lumber of the common yard grades is likely to have a moisture content of 15 to 22 percent.

Because the suitability of wood for certain purposes depends largely on the correct moisture content, specific values for particular uses should be stated in specifications. The importance of suitable moisture content values is recognized, and provisions covering them are now incorporated in some grading rules. It should be noted, however, that the moisture content values in the general grading rules may or may not be suitable for a specific use, and, if not, a special moisture content provision should be made in the specifications.

Storage of Lumber at Yards

Lumber, when received at a distributor's lumber yard, may be practically green, partially seasoned, or thoroughly seasoned. If green or partially seasoned, the stock should be open piled on stickers and protected from sunshine and precipitation by a tight roof (3, 7). If the stock is seasoned to a moisture content of less than 20 percent, it is good practice to pile "solid," board on board, in a shed that will afford ample protection against sunshine and precipitation. If it is desired to reduce the moisture content still further, however, the lumber should be piled with stickers.

Lumber that has a moisture content higher than 20 percent is likely to become stained or decayed when solid piled. On the other hand, lumber seasoned to a moisture content of less than 20 percent is likely to stain or decay if it becomes wet.

The foregoing relates primarily to such items as sheathing, shiplap, studs, and joists. With flooring and interior trim, it is advisable to provide heated storage during damp weather in order to maintain the lumber at the desired moisture content.

The moisture content of lumber items in storage can be maintained by control of the temperature within the shed. If there is no source of moisture except that contained in the outdoor air, the proper shed temperature required to maintain a given moisture content can be determined by the use of figure 9. This chart shows equilibrium moisture content values of wood obtained on heating or cooling outdoor air at any temperature and relative humidity. For example, if the outdoor temperature is 30° F., the relative humidity is 80 percent, and the desired moisture content of the lumber is 8 percent, proceed as follows: from the intersection of the (vertical) 30°-temperature line and the (horizontal) 80-percent relative humidity line, extend a line midway between the adjacent (concave) vapor pressure lines until it intersects a line midway between the 7 and 9 percent moisture content lines indicated on the right-hand ordinate. The reading on the bottom scale at the point of the second intersection is about 47° F. In other words, under the conditions stated, the moisture content of the flooring can be maintained at 8 percent

merely by heating the air to 47° F. In northern areas, heat is required primarily during the winter when the outdoor relative humidity is high, and the equilibrium moisture content of wood exposed to outdoor air may be 15 to 20 percent. If the temperature of the storage shed is kept 10° F. higher than the outdoor temperature the lumber will usually be brought to or maintained at a 10 percent moisture content. If the temperature is increased 20° F. the moisture content will be about 7 percent. During cold weather, if the storage shed contains any water lines the temperature should not be allowed to drop below 32° F.

Care of Lumber and Finish During Construction

Lumber and Dimension

Ordinarily, green lumber should not be used in the construction of a building. Green studs, however, are commonly used, and their drying and shrinking during the course of building does not usually result in much damage. When green stud material is used for wall plates or caps, the resulting shrinkage is more likely to be detrimental. Dry lumber received at the building site should be protected against wetting. It may be solid piled on three timbers laid on the ground, and the pile covered with roll roofing or water-resistant paper. Unless the lumber pile is protected against precipitation, stickers about 4 feet apart should separate the layers of lumber.

Lumber that is received in the green or nearly green condition, or lumber that has been used for concrete forms, should be piled with stickers for more thorough drying before it is built into the structure.

Lumber, whether dry or green, should be protected from alternate wetting by rain and drying by direct sunshine in order to reduce checking and warping.

Frequently in the construction of houses, the garage, if detached, can be built first and will serve as an excellent storage space for sheathing, siding, studs, and joists.

Finish Floor

Cracks develop in flooring if it absorbs moisture either before or after it is laid and then shrinks when the building is heated (11). Such cracks can be greatly reduced, if not entirely eliminated, by observing the following practices: (1) specify flooring manufactured according to association rules and sold by dealers that protect it properly; (2) do not allow the flooring to be delivered on a damp or rainy day or before the masonry and plaster walls are dry; (3) eliminate all badly crooked pieces or use them in inconspicuous places; and heat the building.

Better and smoother sanding and finishing can be done when the house is warm and the wood has been kept dry. One approximate method of determining whether the air in a building is dry enough to permit the delivery and installation of flooring and other interior woodwork is to take two readings on a wet-and-dry-

bulb hygrometer on each of several days. These readings are best taken near the floor and walls at 7 a.m. and 5 p.m. The corresponding relative humidity values should be averaged. If the equilibrium moisture content corresponding to the average relative humidity is found to be about 8 percent from table 1, it may be assumed that the atmosphere within the building is dry enough to have the woodwork delivered and installed. The correct equilibrium moisture content conditions should then be maintained until the building is occupied.

Interior Finish

In a building under construction, the relative humidity will average higher than it will in an occupied house because of the moisture that evaporates from green concrete, brickwork, plaster, and even from the structural wood members. The average temperature will also be lower, because workmen prefer a lower temperature than is agreeable in an occupied house. Under such conditions the finish tends to have a higher moisture content during construction than it would have later during occupancy.

Before any interior finish is delivered, the outside doors and windows should be hung and in place so that they may be kept closed at night and in this way hold the conditions of the interior as close as possible to the higher temperature and lower humidity that ordinarily prevail during the day. Such protection may be sufficient during the dry summer weather, but during damp or cool weather it is highly desirable that some heat be maintained in the house, particularly at night (11). Whenever possible, the heating plant should be placed in the house before the interior trim goes in, so as to be available as a means of supplying the necessary heat. Portable heaters may be used. The temperatures during the night should be maintained at about 15° F. above outside temperatures and not be allowed to drop below about 70° F. during the summer or 62° to 65° F. when outside temperatures are below freezing.

After buildings have thoroughly dried, there is less need for heat, but unoccupied houses, new or old, should not be allowed to stand without some heat during the winter. A temperature of about 15° F. above outside temperatures and above freezing at all times will be sufficient to keep the woodwork, finish, and other parts of the house from being affected by dampness or frost.

Plastering

During a plastering operation in a moderate-sized 6-room house approximately 1,000 pounds of water are used, all of which must be evaporated before the house is ready for the interior finish. Failure to provide ventilation adequate to remove this evaporated moisture means trouble later because of the moisture absorbed by the framework. It also causes paint on exterior finish and siding to blister. During warm, dry, summer weather with the windows wide open, this moisture is practically gone within a week after the final coat of plaster is applied. During damp, cold weather, drying is retarded accordingly. Adequate ventilation should be provided at all times of the year, as the evaporated moisture is air-borne, and a large volume of air is required to carry away the amount of water involved.

When the heating system or portable heaters are used to prevent freezing of plaster and to hasten its drying, the windows should be properly adjusted to allow the escape of the evaporated moisture. Even in the coldest weather, the windows on the leeward side of the house should be opened 2 or 3 inches, preferably from the top.

Determination of Moisture Content

The amount of moisture in wood is ordinarily expressed as a percentage of the weight of the wood when oven-dry. Three distinct methods of determining moisture content are described below. The oven-drying method is probably the most nearly exact, but is slow and necessitates cutting the wood; the distillation method is necessary if the wood contains creosote or other volatile oils; the electrical method is the most rapid and does not necessitate cutting the material.

Oven-drying Method

In the oven-drying method (4) cross sections, about 1 inch long in the direction of the grain, are cut from representative boards of a lot of lumber. These sections should be cut at least 1 foot from the ends of the boards to avoid the effect of end drying, and should be free from knots and other irregularities, such as bark and pitch pockets.

Each section is immediately weighed, before any drying or adsorption of moisture has taken place, and is then placed in an oven heated to 212° to 221° F. and kept there until it reaches constant weight. If the section cannot be weighed immediately after it is cut, it should be wrapped in metal foil until it can be weighed. In the oven, a section will reach a constant weight in 12 to 48 hours. For weighing ordinary moisture content sections, balances having a capacity of about 200 grams and sensitive to 0.05 gram are recommended.

Both steam and electric ovens are in common use for drying moisture-determination sections. The sections, with either type of oven, should be open piled in order to permit good circulation of air, especially around the end-grain surfaces, and thus hasten drying.

The constant or oven-dry weight and the weight of the section when cut are used to determine the percentage moisture content following formula:

$$\text{Percent moisture content} = \frac{\text{weight when cut} - \text{oven-dry weight}}{\text{oven-dry weight}} \times 100$$

Distillation Method

When it is necessary to determine the moisture content of a sample of wood that contains a considerable quantity of volatile oils, oil preservatives, or any other material that might be partly lost by heating, the distillation method should be used (4).

In this method a 25-gram sample of wood in the form of chips, borings, or sawdust is immersed in some water-insoluble oil of low density, such as kerosene, toluene, or xylene, in a flask that can be heated by suitable means and is provided with a reflux condenser discharging into a trap connected to the flask. The trap serves to collect and measure the condensed water and to return the solvent to the flask. The distillation is continued until no more water is obtained in the distillate. The volume, and consequently the weight in grams, of the water in the sample is obtained by direct reading.

Since moisture content is expressed in terms of the oven-dry weight of the oil-free wood, any oil preservative, such as creosote, that the sample may contain must be extracted in order that this weight may be determined. This can be done by carefully transferring the sample or another aliquot to an extraction thimble, placing it in a Soxhlet extractor, and extracting the preservative with a suitable solvent. In addition to the oil preservative, various oil-soluble constituents of the natural wood will be removed by the solvent. After extraction, the oil-free sample is oven dried to constant weight at 212° to 221° F. The moisture content is then calculated on the basis of the dry, oil-free wood.

Electrical Methods

Electrical methods for determining the moisture content of wood make use of such electrical properties of wood as its electrical resistance, dielectric constant, and power factor (1). Electrical moisture meters appeared on the markets about 1930. Instruments are made that determine the moisture content through its effect upon the direct-current electrical resistance of wood and its effect on capacity and losses of a condenser in a high-frequency circuit in which the wood serves as the dielectric material of the condenser.

Although some meters are calibrated to cover a range of 4 to 120 percent, the operating range of most meters is 7 to 25 percent. Above and below these values the readings are inaccurate. Within the range of 7 to 25 percent, electrical moisture meters should read within ± 1 percent of the moisture content, as determined by the oven-drying method. To obtain accurate readings, the instruments should be in good adjustment, and used according to the manufacturer's instructions, which include corrections for various species and cover lumber up to 1-1/2 inches thick or thicker lumber that is known to be of uniform moisture content.

Some judgment must be exercised in the use of electrical meters. They should not be used on dry lumber that has been wet by rain or exposed to damp conditions that have caused the surfaces to become wet. Preferably, meters should not be used on very cold or hot lumber. Most meters are calibrated at 70° F. An approximate temperature correction for resistance-type meters is the adding

of 1 percent to the meter reading for each 20° F. below 70° F., and the subtracting of 1 percent for each 20° F. above 70° F.

The electrical method's principal advantage over the oven-drying method, is its speed and convenience. The time required to determine the moisture content of any piece of wood is only a few seconds. It is, therefore, adaptable to sorting lumber on the basis of moisture content, and can be used to measure the moisture content of wood installed in a building. With the electrical method, the piece of wood is not cut or mutilated except for the driving of a few small needles into the wood to serve as electrodes for the resistance-type meters.

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TABLE 1.—*Relative humidity* [1] *and equilibrium moisture content* [2] *table for use with dry-bulb temperatures and wet-bulb depressions*

Temperature dry bulb (°F.)	Wet bulb—depression (°F.)																																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	32	34	36	38	40	45	50
30	89	78	67	57	46	36	27	17	6																												
		15.9	*12.9*	*10.8*	*9.0*	*7.4*	*5.7*	*3.9*	*1.6*																										
35	90	81	72	63	54	45	37	28	19	11	3																								
		16.8	*13.9*	*11.9*	*10.3*	*8.8*	*7.4*	*6.0*	*4.5*	*2.9*	*0.8*																								
40	92	83	75	68	60	52	45	37	29	22	15	8																							
		17.6	*14.8*	*12.9*	*11.2*	*9.9*	*8.6*	*7.4*	*6.2*	*5.0*	*3.5*	*1.9*																							
45	93	85	78	72	64	58	51	44	37	31	25	19	12	6																					
		18.3	*15.6*	*13.7*	*12.0*	*10.7*	*9.5*	*8.5*	*7.5*	*6.5*	*5.3*	*4.2*	*2.9*	*1.5*																					
50	93	86	80	74	68	62	56	50	44	38	32	27	21	16	10	5																			
		19.0	*16.3*	*14.4*	*12.7*	*11.5*	*10.3*	*9.4*	*8.5*	*7.6*	*6.7*	*5.7*	*4.8*	*3.9*	*2.8*	*1.5*																			
55	94	88	82	76	70	65	60	54	49	44	39	34	28	24	19	14	9	5																	
		19.5	*16.9*	*15.1*	*13.4*	*12.2*	*11.0*	*10.1*	*9.3*	*8.4*	*7.6*	*6.8*	*6.0*	*5.3*	*4.5*	*3.6*	*2.6*	*1.8*																	
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1														
		19.9	*17.4*	*15.6*	*13.9*	*12.7*	*11.6*	*10.7*	*9.9*	*9.1*	*8.3*	*7.6*	*6.9*	*6.3*	*5.6*	*4.9*	*4.1*	*3.2*	*2.3*	*1.3*	*0.2*														
65	95	90	84	80	75	70	66	61	56	52	48	44	39	36	32	27	24	20	16	13	8	6	2												
		20.3	*17.8*	*16.1*	*14.4*	*13.3*	*12.1*	*11.2*	*10.4*	*9.7*	*8.9*	*8.3*	*7.7*	*7.1*	*6.5*	*6.8*	*5.2*	*4.5*	*3.8*	*3.0*	*2.3*	*1.4*	*0.4*												
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3										
		20.6	*18.2*	*16.5*	*14.9*	*13.7*	*12.5*	*11.6*	*10.9*	*10.1*	*9.4*	*8.8*	*8.3*	*7.7*	*7.2*	*6.6*	*6.0*	*5.5*	*4.9*	*4.3*	*3.7*	*2.9*	*2.3*	*1.5*	*0.7*										
75	95	91	86	82	78	74	70	66	62	58	54	51	47	44	41	37	34	31	28	24	21	18	15	12	10	7	4	1							
		20.9	*18.5*	*16.8*	*15.2*	*14.0*	*12.9*	*12.0*	*11.2*	*10.5*	*9.8*	*9.3*	*8.7*	*8.2*	*7.7*	*7.2*	*6.7*	*6.2*	*5.6*	*5.1*	*4.7*	*4.1*	*3.5*	*2.9*	*2.3*	*1.7*	*0.9*	*0.2*							
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15	12	10	7	5	3					
		21.0	*18.7*	*17.0*	*15.5*	*14.3*	*13.2*	*12.3*	*11.5*	*10.9*	*10.1*	*9.7*	*9.1*	*8.6*	*8.1*	*7.7*	*7.2*	*6.8*	*6.3*	*5.8*	*5.4*	*5.0*	*4.5*	*4.0*	*3.5*	*3.0*	*2.4*	*1.8*	*1.1*	*0.3*					
85	96	92	88	84	80	76	73	70	66	63	59	56	53	50	47	44	41	38	36	33	30	28	25	23	20	18	15	13	11	9	4				
		21.2	*18.8*	*17.2*	*15.7*	*14.5*	*13.5*	*12.5*	*11.8*	*11.2*	*10.5*	*10.0*	*9.5*	*9.0*	*8.5*	*8.1*	*7.6*	*7.2*	*6.7*	*6.3*	*6.0*	*5.6*	*5.2*	*4.8*	*4.3*	*3.9*	*3.4*	*3.0*	*2.4*	*1.7*	*0.9*				
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	24	22	19	17	15	13	9	5	1		
		21.3	*18.9*	*17.3*	*15.9*	*14.7*	*13.7*	*12.8*	*12.0*	*11.4*	*10.7*	*10.2*	*9.7*	*9.3*	*8.8*	*8.4*	*8.0*	*7.6*	*7.2*	*6.8*	*6.5*	*6.1*	*5.7*	*5.3*	*4.9*	*4.4*	*4.0*	*3.3*	*3.8*	*2.8*	*2.1*	*1.3*	*0.4*		
95	96	92	89	85	82	79	75	72	69	66	63	60	57	55	52	49	46	44	42	39	37	34	32	30	28	26	23	22	20	17	14	10	6	2	
		21.3	*19.0*	*17.4*	*16.1*	*14.9*	*13.9*	*12.9*	*12.2*	*11.6*	*11.0*	*10.5*	*10.0*	*9.5*	*9.1*	*8.7*	*8.2*	*7.9*	*7.5*	*7.1*	*6.8*	*6.4*	*6.1*	*5.7*	*5.3*	*5*	*4.8*	*4*	*4*	*3.6*	*3.0*	*2.5*	*1.5*	*0.6*	
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	30	28	26	24	22	21	17	13	10	7	4
		21.3	*19.0*	*17.5*	*16.1*	*15.0*	*13.9*	*13.1*	*12.4*	*11.8*	*11.2*	*10.6*	*10.1*	*9.6*	*9.2*	*8.9*	*8.5*	*8.1*	*7.8*	*7.4*	*7.0*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5*	*4*	*4*	*4*	*3.4*	*2.4*	*1.6*	*0.7*	
105	96	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48	46	44	42	40	37	35	34	31	29	28	26	24	20	17	14	11	8
		21.4	*19.0*	*17.5*	*16.2*	*15.1*	*14.0*	*13.2*	*12.6*	*11.9*	*11.3*	*10.8*	*10.3*	*9.8*	*9.4*	*9.0*	*8.7*	*8.3*	*7.9*	*7.6*	*7.3*	*6.9*	*6.7*	*6.4*	*6.1*	*5.8*	*5.4*	*4.9*	*4.6*	*4*	*3.8*	*3.1*	*2.4*	*1.5*	
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	36	34	32	30	28	26	23	20	17	14	11
		21.4	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.3*	*12.6*	*11.9*	*11.3*	*10.8*	*10.3*	*9.9*	*9.4*	*9.0*	*8.6*	*8.3*	*7.9*	*7.5*	*7.2*	*6.8*	*6.5*	*6.2*	*5.9*	*5.6*	*5.2*	*4.8*	*4.4*	*4.0*	*3.5*	*3.0*	*2.5*	*1.9*	
115	97	93	90	88	85	82	79	76	74	71	68	66	63	61	58	56	54	52	50	48	45	43	41	39	38	36	34	32	30	29	26	23	20	17	14
		21.4	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.3*	*12.6*	*12.0*	*11.3*	*10.8*	*10.3*	*9.9*	*9.5*	*9.1*	*8.7*	*8.4*	*8.0*	*7.7*	*7.4*	*7.0*	*6.7*	*6.4*	*6.1*	*5.8*	*5.5*	*5.2*	*4.8*	*4.4*	*4.0*	*3.5*	*2.9*	*2.3*	*1.6*
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	56	53	51	49	47	45	43	41	40	38	36	34	33	31	28	25	22	19	17
		21.3	*19.0*	*17.4*	*16.2*	*15.1*	*14.1*	*13.3*	*12.6*	*12.0*	*11.3*	*10.8*	*10.3*	*9.9*	*9.5*	*9.2*	*8.8*	*8.5*	*8.2*	*7.9*	*7.7*	*7.4*	*7.1*	*6.8*	*6.5*	*6.2*	*5.9*	*5.6*	*5.3*	*5.1*	*4.6*	*4.2*	*3.7*	*3.2*	*2.6*
125	97	94	91	88	86	83	80	77	75	73	70	68	65	63	61	59	57	55	53	51	49	47	45	43	41	39	38	36	35	33	30	27	24	22	19
		21.2	*18.9*	*17.3*	*16.1*	*15.0*	*14.0*	*13.2*	*12.5*	*11.9*	*11.3*	*10.8*	*10.3*	*9.9*	*9.5*	*9.2*	*8.8*	*8.5*	*8.2*	*7.9*	*7.7*	*7.4*	*7.1*	*6.8*	*6.5*	*6.2*	*5.9*	*5.6*	*5.3*	*5.1*	*4.6*	*4.2*	*3.7*	*3.2*	*2.6*
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62	60	58	56	54	52	50	48	47	45	43	41	40	38	37	35	32	29	26	24	21
		21.0	*18.8*	*17.2*	*16.0*	*14.9*	*14.0*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.1*	*9.7*	*9.4*	*9.0*	*8.7*	*8.4*	*8.1*	*7.8*	*7.6*	*7.3*	*7.0*	*6.8*	*6.6*	*6.3*	*6.1*	*5.9*	*5.6*	*5.3*	*4.9*	*4.2*	*3.8*	*3.3*
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58	56	54	53	51	49	47	46	44	43	41	40	38	35	32	30	27	25
		20.7	*18.6*	*16.9*	*15.8*	*14.8*	*13.8*	*13.2*	*12.6*	*12.1*	*11.6*	*11.1*	*10.7*	*10.3*	*9.9*	*9.4*	*9.0*	*8.7*	*8.4*	*8.0*	*7.8*	*7.6*	*7.4*	*7.1*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.1*	*4.8*	*4.4*	*4.1*
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	64	62	60	58	57	55	53	51	49	48	46	45	43	42	41	38	36	33	30	28
		20.2	*18.4*	*16.6*	*15.4*	*14.3*	*13.7*	*13.0*	*12.4*	*11.8*	*11.2*	*10.8*	*10.3*	*9.9*	*9.5*	*9.2*	*8.9*	*8.6*	*8.3*	*8.0*	*7.8*	*7.5*	*7.3*	*7.1*	*6.9*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.2*	*4.9*	*4.5*	*4.2*
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	57	55	53	52	50	49	47	46	44	43	41	38	35	33	31
		19.8	*18.1*	*16.2*	*15.2*	*14.2*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.6*	*10.1*	*9.7*	*9.4*	*9.1*	*8.8*	*8.5*	*8.2*	*7.9*	*7.7*	*7.4*	*7.2*	*7.0*	*6.8*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.9*	*4.6*	*4.3*
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63	62	60	59	57	55	53	52	51	49	48	47	45	43	40	38	35	33
		19.4	*17.7*	*15.8*	*14.8*	*13.9*	*13.2*	*12.4*	*11.8*	*11.3*	*10.8*	*10.4*	*9.9*	*9.6*	*9.2*	*9.0*	*8.6*	*8.4*	*8.0*	*7.8*	*7.6*	*7.3*	*7.2*	*6.9*	*6.7*	*6.6*	*6.4*	*6.2*	*6.0*	*5.7*	*5.5*	*5.2*	*4.9*	*4.6*	*4.4*
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	60	58	57	55	54	52	51	50	48	47	45	42	40	38	35
		18.9	*17.3*	*15.5*	*14.5*	*13.7*	*12.9*	*12.2*	*11.6*	*11.1*	*10.6*	*10.1*	*9.7*	*9.4*	*9.0*	*8.8*	*8.4*	*8.1*	*7.8*	*7.6*	*7.4*	*7.2*	*7.0*	*6.8*	*6.5*	*6.4*	*6.2*	*6.0*	*5.8*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.3*
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71	69	68	66	65	63	62	60	58	57	56	54	53	51	50	49	46	44	42	39	37
		18.5	*16.9*	*15.2*	*14.2*	*13.4*	*12.7*	*12.0*	*11.4*	*10.9*	*10.5*	*10.0*	*9.6*	*9.2*	*8.9*	*8.6*	*8.2*	*7.9*	*7.7*	*7.4*	*7.2*	*7.0*	*6.8*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.5*	*5.3*	*5.0*	*4.8*	*4.5*	*4.4*
200	98	96	94	91	92	90	88	86	84	82	80	79	77	75	74	72	70	69	67	66	64	63	61	60	58	57	55	54	53	52	51	48	46	43	41
		18.1	*16.4*	*14.9*	*14.0*	*13.2*	*12.4*	*11.8*	*11.2*	*10.8*	*10.3*	*9.8*	*9.4*	*9.1*	*8.8*	*8.4*	*8.1*	*7.7*	*7.5*	*7.2*	*7.0*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.6*	*5.4*	*5.2*	*4.9*	*4.7*	*4.5*	*4.3*
210	98	96	94	92	90	88	86	85	83	81	79	78	76	75	73	71	70	68	67	65	64	63	61	60	59	57	56	54	53	52	50	47	45	43	41
		17.7	*16.0*	*14.6*	*13.8*	*13.0*	*12.2*	*11.7*	*11.1*	*10.6*	*10.0*	*9.7*	*9.2*	*9.0*	*8.7*	*8.3*	*8.0*	*7.6*	*7.4*	*7.1*	*6.9*	*6.8*	*6.5*	*6.3*	*6.1*	*5.9*	*5.8*	*5.5*	*5.4*	*5.3*	*5.1*	*4.8*	*4.6*	*4.4*	*4.2*

[1] Relative humidity values in roman type.
[2] Equilibrium moisture content values in italic type.

Table 2.--Recommended moisture content values for various wood items at time of installation

Use of lumber	Moisture content (percentage of weight of oven-dry wood) for --					
	Dry southwestern States[1]		Damp southern coastal States[1]		Remainder of the United States[1]	
	Average[2]	Individual pieces	Average[2]	Individual pieces	Average[2]	Individual pieces
	Percent	Percent	Percent	Percent	Percent	Percent
Interior finish woodwork and softwood flooring	6	4-9	11	8-13	8	5-10
Hardwood flooring	6	5-8	10	9-12	7	6-9
Siding, exterior trim, sheathing, and framing[3]	9	7-12	12	9-14	12	9-14

[1] For limiting range see figure 1.

[2] In general, the moisture content averages have less significance than the range in moisture content permitted in individual pieces. If the moisture content values of all the pieces in a lot fall within the prescribed range, the entire lot will be satisfactory as to moisture content no matter what its average moisture content may be.

[3] Framing lumber of higher moisture content is commonly used in ordinary construction because material of the moisture content specified may not be available except on special order.

Table 3.--Shrinkage values for commercially important woods grown in the United States

Species	Shrinkage (percent of dimension when green)								
	Air-dried to 15 percent moisture content[1] (estimated value)			Kiln-dried to 6 percent moisture content[2] (estimated values)			Oven-dried to 0 percent moisture content (test values)		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Alder, red	2.2	3.6	6.3	3.5	5.8	10.1	4.4	7.3	12.6
Alaska yellow-cedar	1.4	3.0	4.6	2.2	4.8	7.4	2.8	6.0	9.2
Ash:									
Black	2.5	3.9	7.6	4.0	6.2	12.2	5.0	7.8	15.2
Commercial white	2.3	3.8	6.4	3.7	6.0	10.2	4.6	7.5	12.8
Oregon	2.0	4.0	6.6	3.3	6.5	10.6	4.1	8.1	13.2
Aspen	1.8	3.4	5.8	2.8	5.4	9.2	3.5	6.7	11.5
Baldcypress	1.9	3.1	5.2	3.0	5.0	8.4	3.8	6.2	10.5
Basswood	3.3	4.7	7.9	5.3	7.4	12.6	6.6	9.3	15.8
Beech, American	2.6	5.5	8.2	4.1	8.8	13.0	5.1	11.0	16.3
Birch 2/	3.4	4.4	8.2	5.5	7.1	13.0	6.9	8.9	16.3
Birch, paper	3.2	4.3	8.1	5.0	6.9	13.0	6.3	8.6	16.2
Butternut	1.6	3.0	5.1	2.6	4.9	8.2	3.3	6.1	10.2
Cherry, black	1.8	3.6	5.8	3.0	5.7	9.2	3.7	7.1	11.5
Chestnut	1.7	3.4	5.8	2.7	5.4	9.3	3.4	6.7	11.6
Cottonwood:									
Eastern	2.0	4.6	7.0	3.1	7.4	11.3	3.9	9.2	14.1
Northern black	1.8	4.3	6.2	2.9	6.9	9.9	3.6	8.6	12.4
Douglas-fir:									
Coast type	2.5	3.9	5.9	4.0	6.2	9.4	5.0	7.8	11.8
Intermediate type	2.0	3.8	5.4	3.3	6.1	8.7	4.1	7.6	10.9
Rocky Mountain type	1.8	3.1	5.3	2.9	5.0	8.5	3.6	6.2	10.6
Elm:									
American	2.1	4.8	7.3	3.4	7.6	11.7	4.2	9.5	14.6
Rock	2.4	4.0	7.0	3.8	6.5	11.3	4.8	8.1	14.1
Slippery	2.4	4.4	6.9	3.9	7.1	11.0	4.9	8.9	13.8
Fir:									
Balsam	1.4	3.3	5.4	2.2	5.3	8.6	2.8	6.6	10.8
Commercial white 4/	1.6	3.6	4.9	2.6	5.7	7.8	3.2	7.1	9.8
Hackberry	2.4	4.4	6.9	3.8	7.1	11.0	4.8	8.9	13.8
Hemlock:									
Eastern	1.5	3.4	4.8	2.4	5.4	7.8	3.0	6.8	9.7
Western	2.2	4.0	6.0	3.4	6.3	9.5	4.3	7.9	11.9
Hickory:									
Pecan 5/	2.4	4.4	6.8	3.9	7.1	10.9	4.9	8.9	13.6
True 6/	3.6	5.7	9.0	5.8	9.1	14.3	7.3	11.4	17.9
Honey locust	2.1	3.3	5.4	3.4	5.3	8.6	4.2	6.6	10.8
Incense-cedar, California	1.6	2.6	3.8	2.6	4.2	6.1	3.3	5.2	7.6
Larch, western	2.1	4.0	6.6	3.4	6.5	10.6	4.2	8.1	13.2
Locust, black	2.2	3.4	4.9	3.5	5.5	7.8	4.4	6.9	9.8
Magnolia:									
Cucumbertree	2.6	4.4	6.8	4.2	7.0	10.9	5.2	8.8	13.6
Evergreen	2.7	3.3	6.2	4.3	5.3	9.8	5.4	6.6	12.3
Mahogany	1.8	2.4	3.8	2.8	3.8	6.2	3.5	4.8	7.7
Maple:									
Bigleaf	1.8	3.6	5.8	3.0	5.7	9.3	3.7	7.1	11.6
Black	2.4	4.6	7.0	3.8	7.4	11.2	4.8	9.3	14.0
Red	2.0	4.1	6.6	3.2	6.6	10.5	4.0	8.2	13.1
Silver	1.5	3.6	6.0	2.4	5.8	9.6	3.0	7.2	12.0
Sugar	2.4	4.8	7.4	3.9	7.6	11.9	4.9	9.5	14.9
Oak:									
Red 7/	2.2	4.5	7.4	3.4	7.2	11.8	4.3	9.0	14.8
White 8/	2.7	4.6	8.0	4.3	7.4	12.8	5.4	9.3	16.0
Pine:									
Eastern white	1.2	3.0	4.1	1.8	4.8	6.6	2.3	6.0	8.2
Loblolly	2.4	3.7	6.2	3.8	5.9	9.8	4.8	7.4	12.3
Lodgepole	2.2	3.4	5.8	3.6	5.4	9.2	4.5	6.7	11.5
Longleaf	2.6	3.8	6.1	4.1	6.0	9.8	5.1	7.5	12.2
Ponderosa	2.0	3.2	4.8	3.1	5.0	7.7	3.9	6.3	9.6
Red	2.3	3.6	5.8	3.7	5.8	9.2	4.6	7.2	11.5
Shortleaf	2.2	3.8	6.2	3.5	6.2	9.8	4.4	7.7	12.3
Sugar	1.4	2.8	4.0	2.3	4.5	6.3	2.9	5.6	7.9
Western white	2.0	3.7	5.9	3.3	5.9	9.4	4.1	7.4	11.8
Redcedar, eastern	1.6	2.4	3.9	2.5	3.8	6.2	3.1	4.7	7.8
Redcedar, western	1.2	2.5	3.8	1.9	4.0	6.2	2.4	5.0	7.7
Redwood	1.3	2.2	3.4	2.1	3.5	5.4	2.6	4.4	6.8
Spruce:									
Eastern 9/	2.2	3.8	6.3	3.4	6.2	10.1	4.3	7.7	12.6
Engelmann	1.7	3.3	5.2	2.7	5.3	8.3	3.4	6.6	10.4
Sitka	2.2	3.8	5.8	3.4	6.0	9.2	4.3	7.5	11.5
Sweetgum	2.6	5.0	7.5	4.2	7.9	12.0	5.2	9.9	15.0
Sycamore, American	2.6	3.8	7.1	4.1	5.3	11.4	5.1	7.6	14.2
Tamarack	1.8	3.7	6.8	3.0	5.9	10.9	3.7	7.4	13.6
Tupelo:									
Black	2.2	3.8	7.0	3.5	6.2	11.1	4.4	7.7	13.9
Water	2.1	3.8	6.2	3.4	6.1	10.0	4.2	7.6	12.5
Walnut, black	2.6	3.6	5.7	4.2	5.7	9.0	5.2	7.1	11.3
White-cedar:									
Atlantic	1.4	2.6	4.2	2.2	4.2	6.7	2.8	5.2	8.4
Northern	1.0	2.4	3.5	1.7	3.8	5.6	2.1	4.7	7.0
Port Orford	2.3	3.4	5.0	3.7	5.5	8.1	4.6	6.9	10.1
Yellow-poplar	2.0	3.6	6.2	3.2	5.7	9.8	4.0	7.1	12.3

1/ These shrinkage values have been taken as one-half the shrinkage to the oven-dry condition as given in the last three columns of this table.

2/ These shrinkage values have been taken as four-fifths of the shrinkage to the oven-dry condition as given in the last three columns of this table.

3/ Average of sweet birch and yellow birch.

4/ Average of grand fir and white fir.

5/ Average of bitternut hickory, nutmeg hickory, water hickory, and pecan.

6/ Average of shellbark hickory, mockernut hickory, pignut hickory, and shagbark hickory.

7/ Average of black oak, laurel oak, pin oak, northern red oak, scarlet oak, southern red oak, swamp red oak, water oak and willow oak.

8/ Average of bur oak, chestnut oak, post oak, swamp chestnut oak, swamp white oak, and white oak.

9/ Average of black spruce, red spruce, and white spruce.

Rept. No. R1903-7

Z M 88256 F

Table 4.--Average moisture content of green wood

Species	Moisture content[1]		
	Heartwood	Sapwood	Mixed heartwood and sapwood
	Percent	Percent	Percent
SOFTWOODS			
Baldcypress	121	171	
Cedar:			
Alaska yellow	32	166	
Eastern red	33		
California incense	40	213	
Northern white			55
Port Orford white	50	98	
Atlantic white			35
Western red	58	249	
Douglas-fir:			
Coast type	37	115	
Intermediate type	34	154	
Rocky Mountain type	30	112	
Fir:			
Alpine			47
Balsam			117
Grand (lowland white)	91	136	
Noble	34	115	
Pacific silver	55	164	
Red			108
White	98	160	
Hemlock:			
Eastern	97	119	
Western	85	170	
Larch, western	54	119	
Pine:			
Eastern white			68
Lodgepole	41	120	
Ponderosa	40	148	
Red	32	134	
Southern yellow:			
Loblolly	33	110	
Longleaf	31	106	
Shortleaf	32	122	
Sugar	98	219	
Western white (Idaho)	62	148	

(Sheet 1 of 4)

Table 4.--Average moisture content of green wood (continued)

Species	Moisture content[1]		
	Heartwood	Sapwood	Mixed heartwood and sapwood
	Percent	Percent	Percent
SOFTWOODS (continued)			
Redwood:			
Second-growth			127
Old-growth	86	210	
Spruce:			
Eastern	34	128	
Engelmann	51	173	
Sitka	41	142	
Tamarack (eastern larch)	49		
HARDWOODS			
Alder, red		97	
Apple			46
Ash:			
Black	95		
White	46	44	
Aspen (quaking and bigtooth)	95	113	
Basswood	81	133	
Beech	55	72	
Birch:			
Paper	89	72	
Yellow	74	72	
Buckeye, yellow			141
Butternut			104
Cherry, black	58		
Chestnut	120		
Chinquapin			134
Cottonwood, black	162	146	

Table 4.--Average moisture content of green wood (continued)

Species	Moisture content[1]		
	Heartwood	Sapwood	Mixed heartwood and sapwood
	Percent	Percent	Percent
HARDWOODS (continued)			
Dogwood			62
Elm:			
American	95	92	
Rock	44	57	
Hackberry	61	65	
Hickory	65	50	
Holly			82
Hophornbeam (ironwood)			52
Laurel, California (Oregon myrtle)			65
Locust, black			40
Madrone			81
Magnolia	80	104	
Maple:			
Silver (soft)	58	97	
Sugar (hard)	65	72	
Oak:			
California black	76	75	
Live			50
Northern red	80	69	
Southern red	83	75	
Southern swamp	79	66	
Tan			89
White	64	78	
Osage-orange			31
Persimmon			58
Sweetgum	79	137	

Table 4.--Average moisture content of green wood (continued)

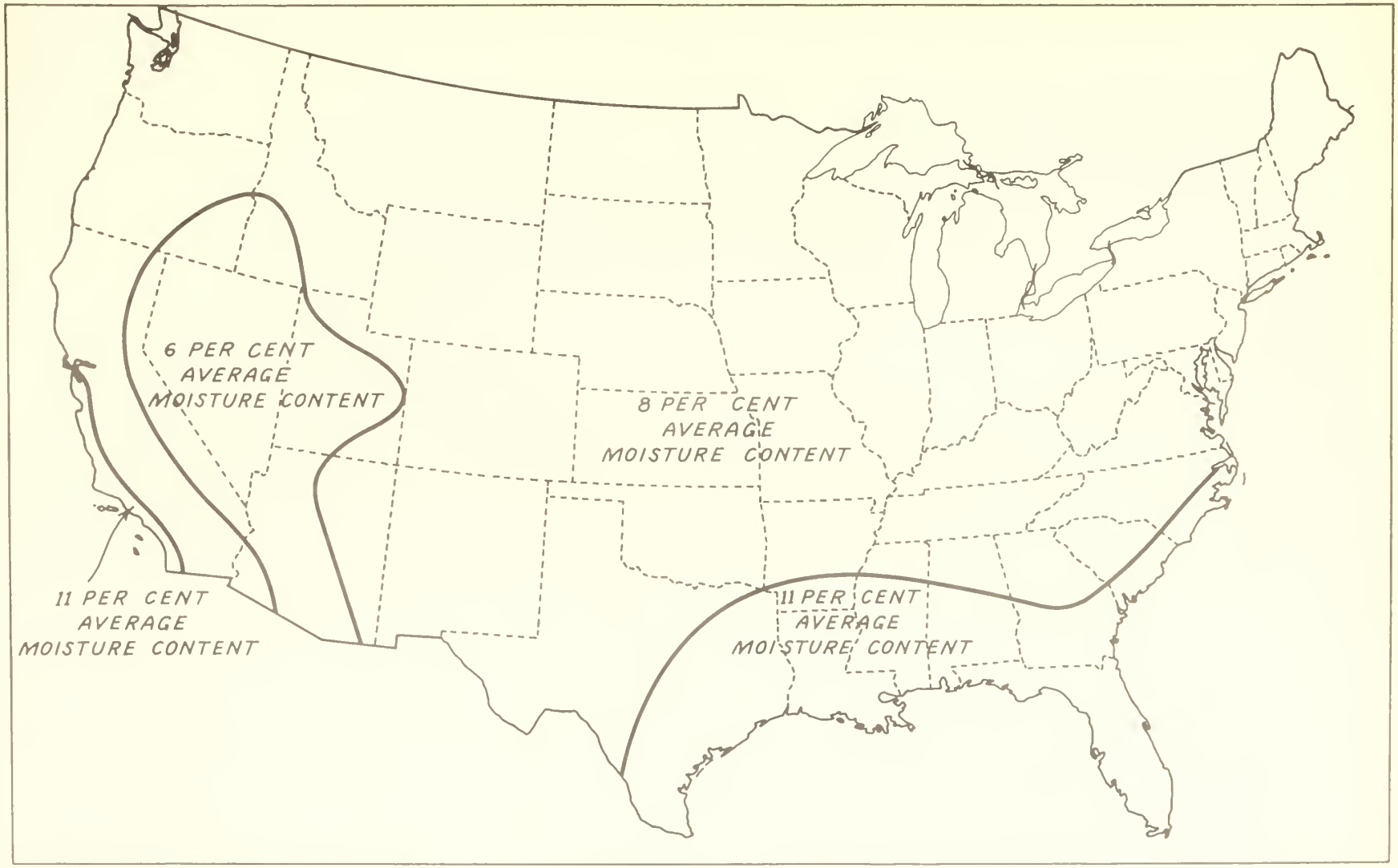
Species	Moisture content[1]		
	Heartwood	Sapwood	Mixed heartwood and sapwood
	Percent	Percent	Percent
HARDWOODS (continued)			
Sycamore	114	130	
Tupelo:			
Black	87	115	
Water	158		
Walnut, black	90	73	
Willow, black			139
Yellow-poplar	83	106	

[1] Based on oven-dried weight.

(Concluded)

Figure 1.--Recommended moisture content averages for interior-finishing woodwork for use in various parts of the United States.

ZM 20143 F


6 PER CENT
AVERAGE
MOISTURE CONTENT
8 PER CENT
AVERAGE
MOISTURE CONTENT
11 PER CENT
AVERAGE
MOISTURE CONTENT
11 PER CENT
AVERAGE
MOISTURE CONTENT

ZM201431

Figure 2.--Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of the annual rings. Tangential shrinkage is about twice as great as radial.

ZM 12494 F

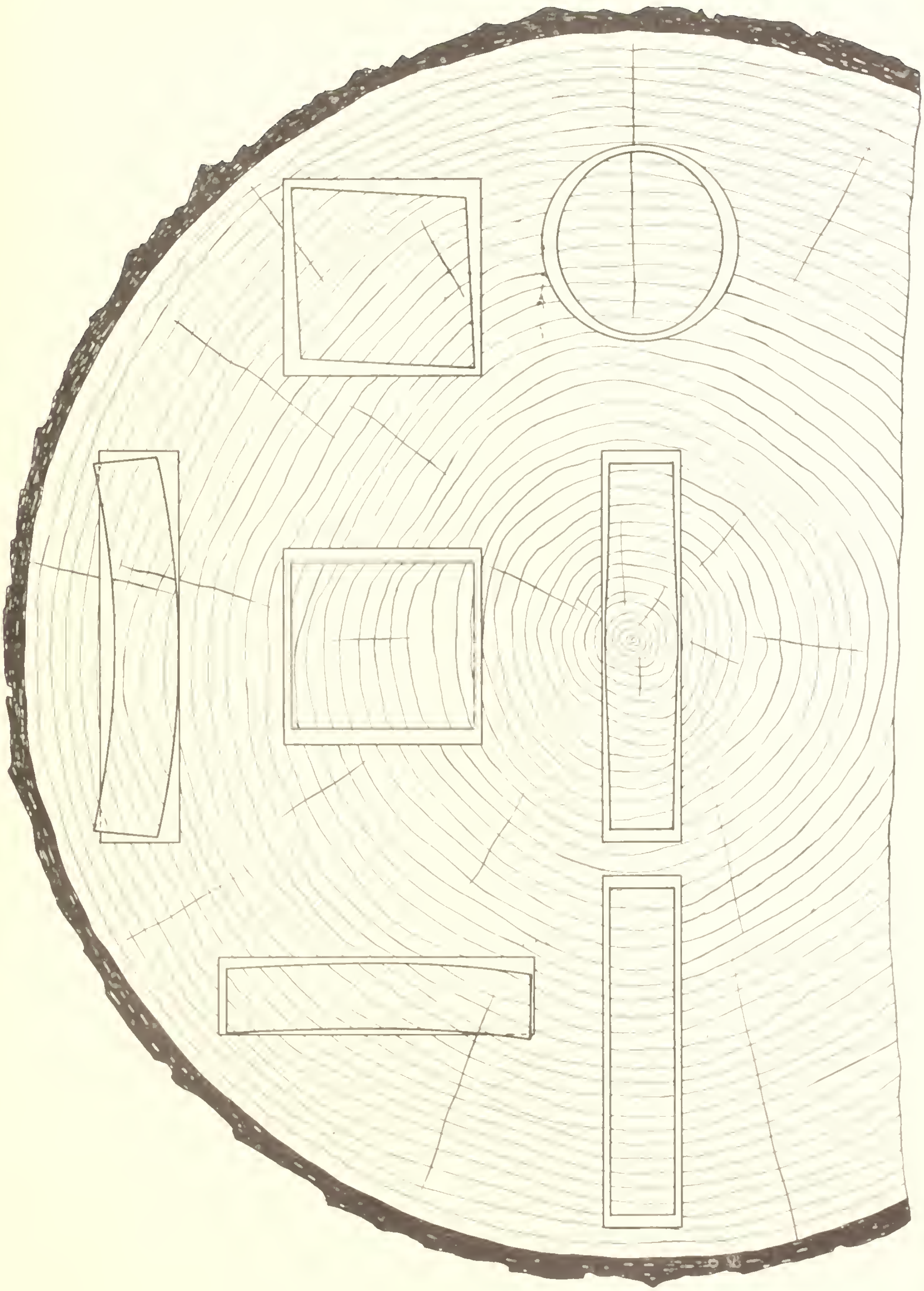


Figure 3.--Typical moisture-shrinkage curves. These curves are for Douglas-fir and southern yellow pine and may be used for estimating the amount of change in dimension that will take place with change in the moisture content of the wood.

ZM 22048 F

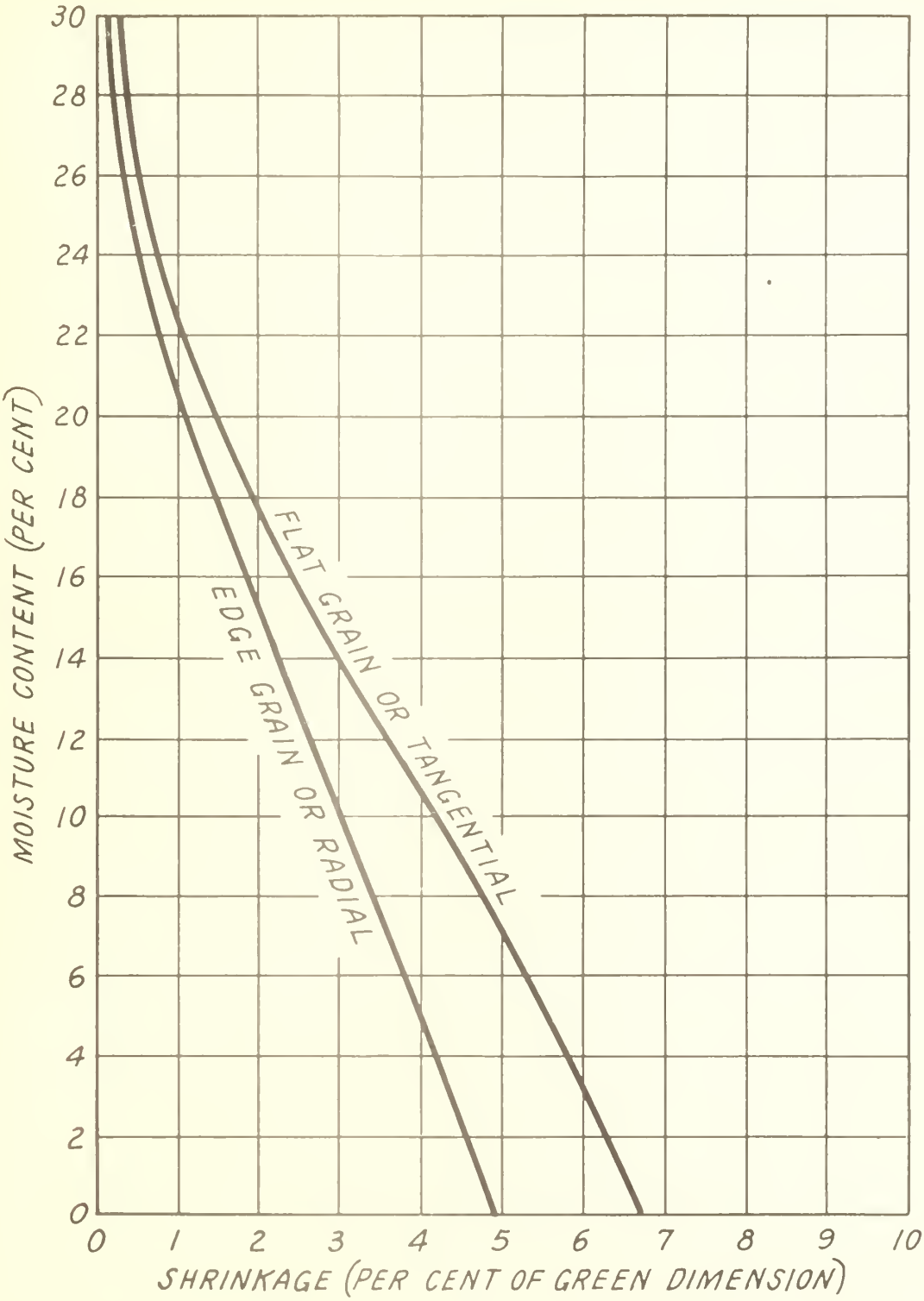

MOISTURE CONTENT (PER CENT)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
FLAT GRAIN OR TANGENTIAL
EDGE GRAIN OR RADIAL
0
1
2
3
4
5
6
7
8
9
10
SHRINKAGE (PER CENT OF GREEN DIMENSION)

Figure 4.--Joists run over top of girder increase the vertical height of the wood used across the grain and increase subsequent shrinkage.

ZM 22072 F

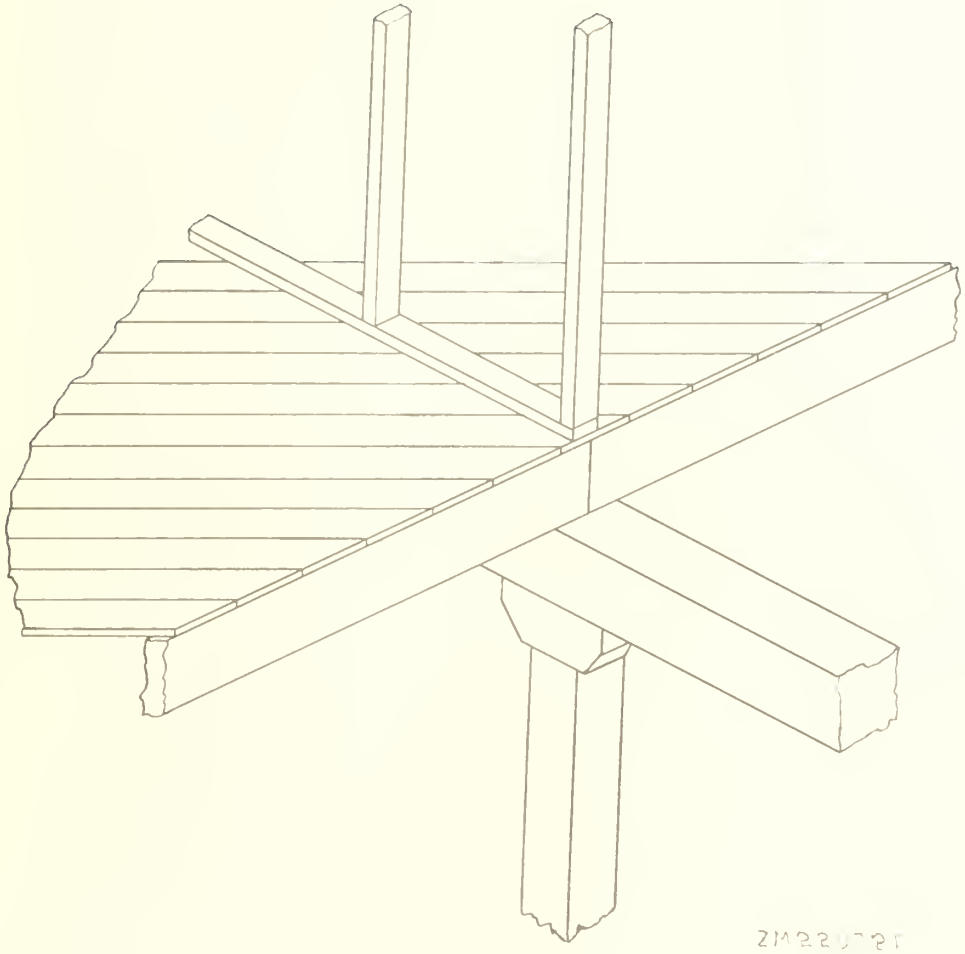


Figure 5.--Joists bear on ledger strips to minimize shrinkage.

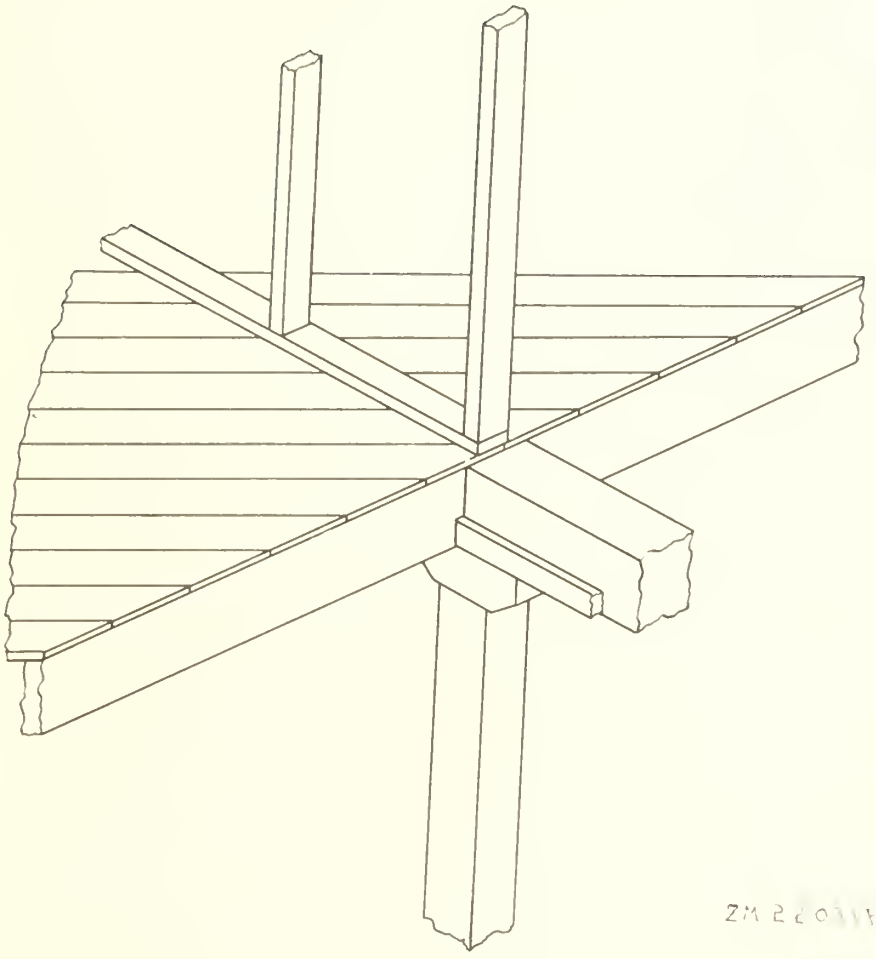
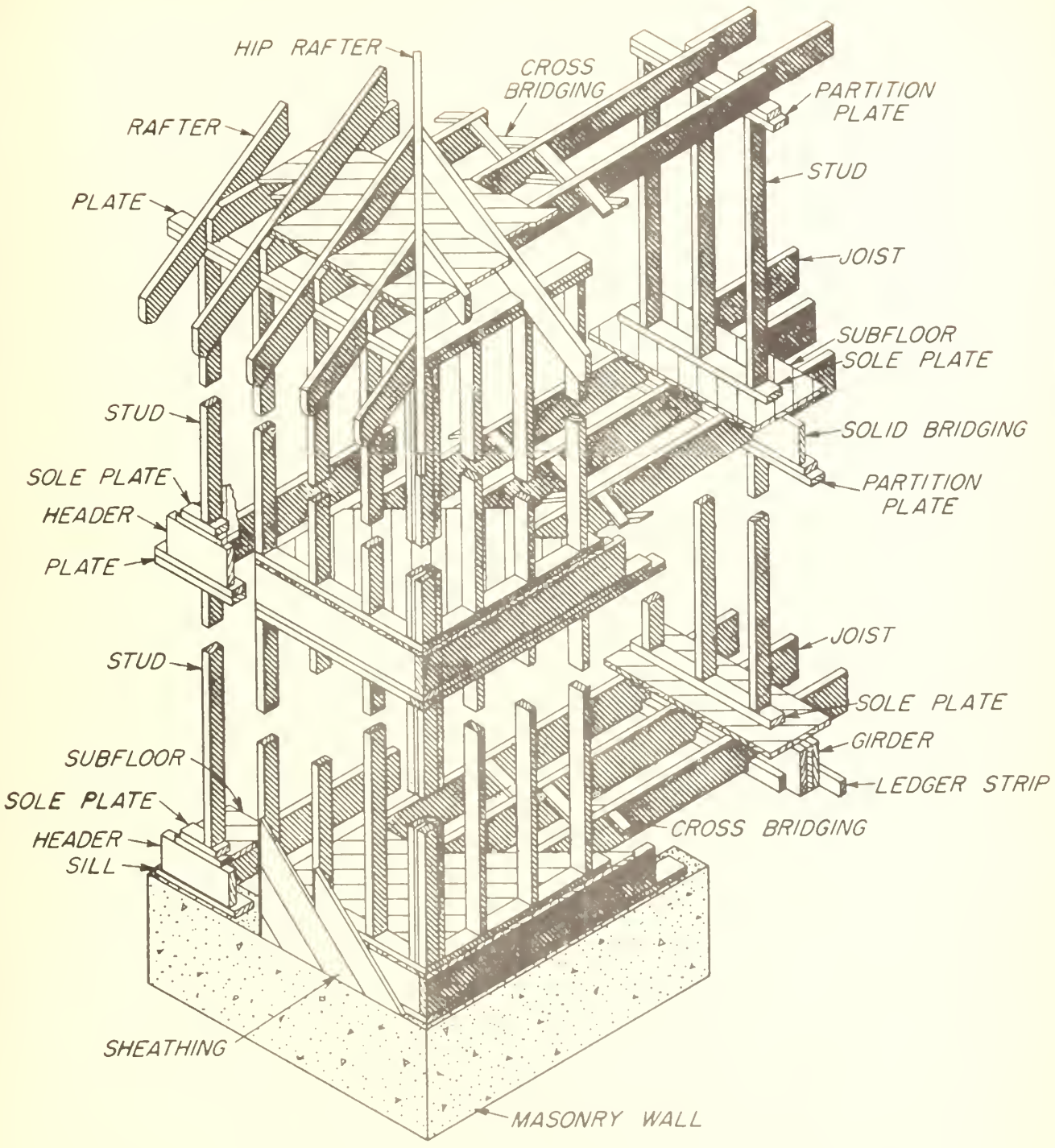


Figure 6.--Platform-frame construction.

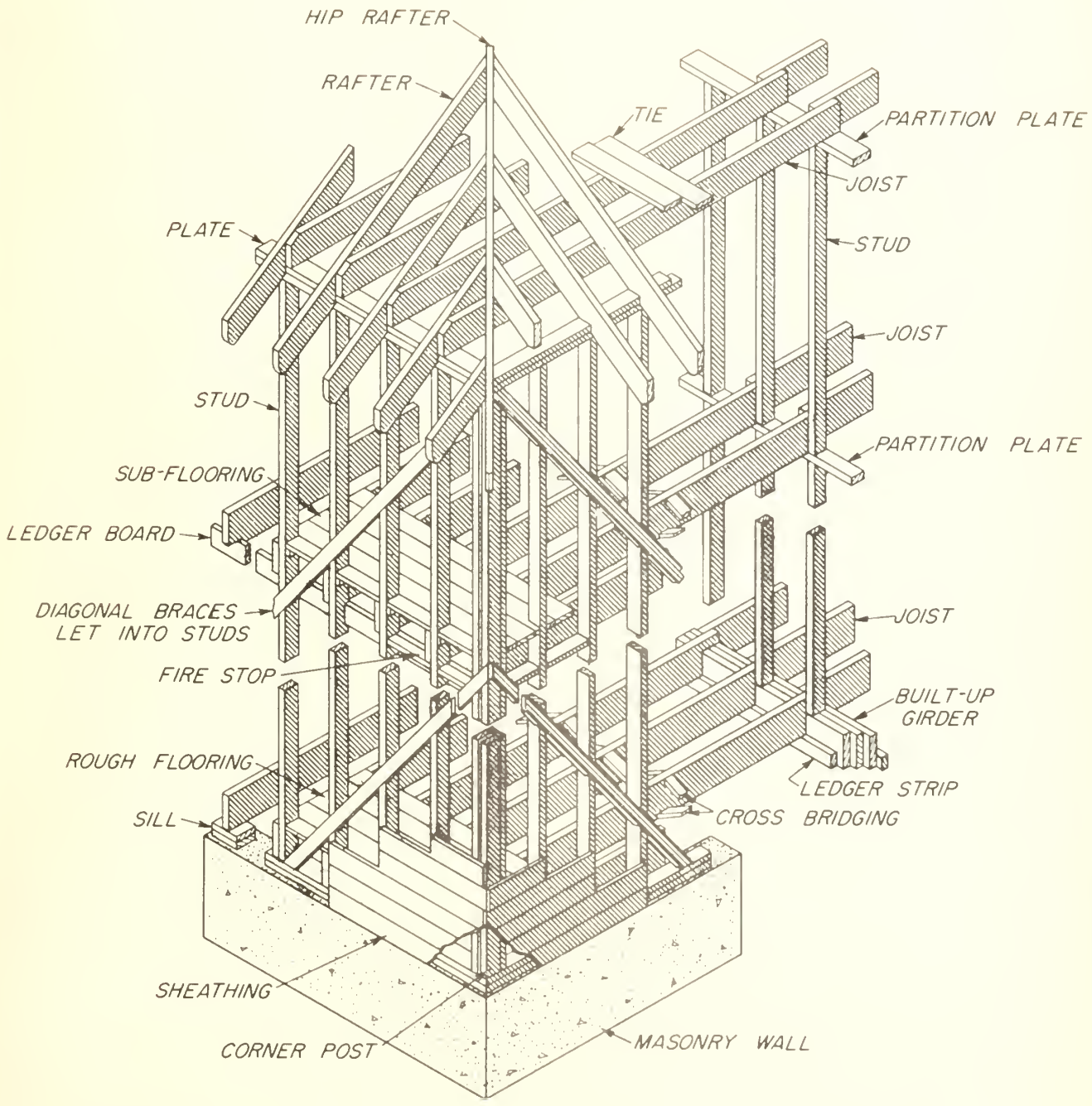
ZM 88257 F


HIP RAFTER
CROSS BRIDGING
PARTITION PLATE
RAFTER
STUD
PLATE
JOIST
SUBFLOOR
SOLE PLATE
STUD
SOLID BRIDGING
SOLE PLATE
PARTITION PLATE
HEADER
PLATE
JOIST
STUD
SOLE PLATE
GIRDER
SUBFLOOR
LEDGER STRIP
SOLE PLATE
CROSS BRIDGING
HEADER
SILL
SHEATHING
MASONRY WALL

Z M 88257 F

Figure 7.--Balloon-frame construction.

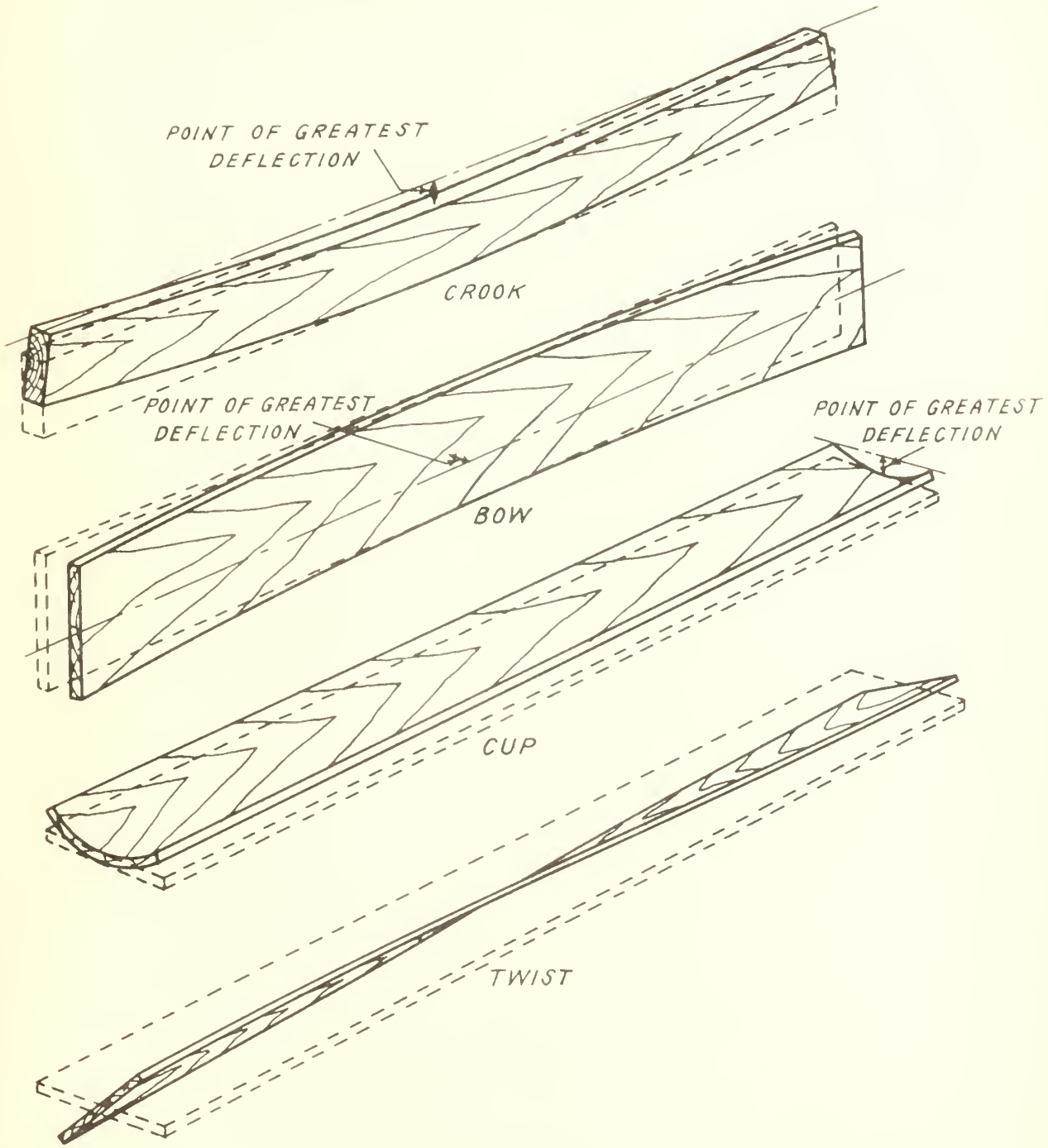
ZM 88258 F


HIP RAFTER
RAFTER
TIE
PARTITION PLATE
JOIST
PLATE
STUD
JOIST
STUD
PARTITION PLATE
SUB-FLOORING
LEDGER BOARD
DIAGONAL BRACES
LET INTO STUDS
JOIST
FIRE STOP
BUILT-UP
GIRDER
ROUGH FLOORING
LEDGER STRIP
SILL
CROSS BRIDGING
SHEATHING
CORNER POST
MASONRY WALL

Z M 88258 F

Figure 8.--Various kinds of warp.

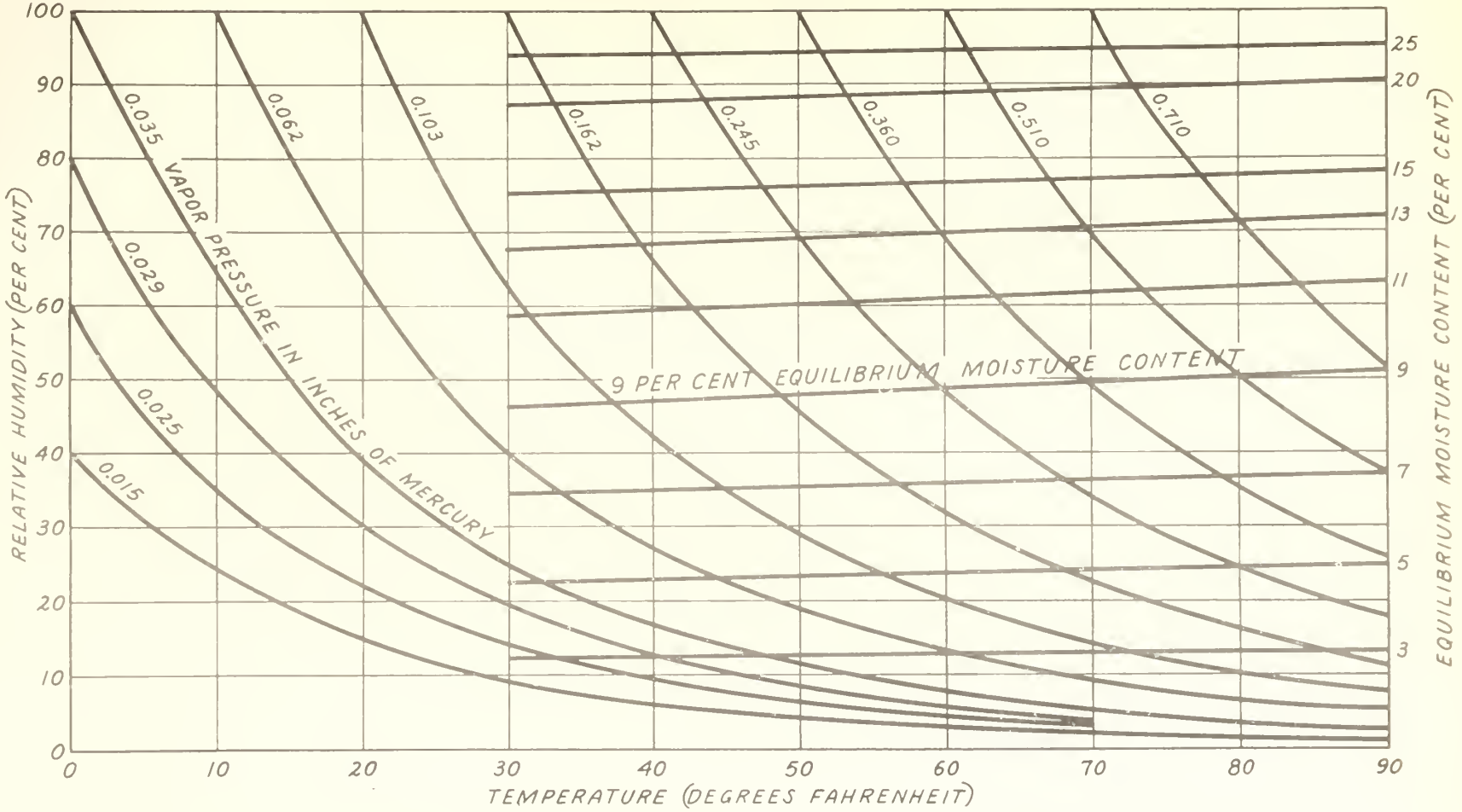
ZM 66723 F


POINT OF GREATEST DEFLECTION
CROOK
POINT OF GREATEST DEFLECTION
BOW
POINT OF GREATEST DEFLECTION
CUP
TWIST

ZM167235

Figure 9.--Relationship of relative humidity, vapor pressure, equilibrium moisture content, and temperature.

ZM 17222 F


RELATIVE HUMIDITY (PER CENT)
EQUILIBRIUM MOISTURE CONTENT (PER CENT)
TEMPERATURE (DEGREES FAHRENHEIT)
VAPOR PRESSURE IN INCHES OF MERCURY
0.035
0.062
0.103
0.162
0.245
0.360
0.510
0.710
0.029
0.025
0.015
9 PER CENT EQUILIBRIUM MOISTURE CONTENT
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
25
20
15
13
11
9
7
5
3

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